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H. Stegmann, W. Kindermann, and A. Schnabel

Abteilung Sport- und Leistungsmedizin (Leiter: Prof. Dr. med. W. Kindermann) der Universität des Saarlandes, Saarbrücken

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Abstract

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Exercise with stepwise increasing work loads until exhaustion leads to a curvilinear increase of lactate in blood and typical lactate kinetics in the post-exercise period. Lactate kinetics in blood during exercise and recovery results from diffusion along gradients between muscle and blood and simultaneous elimination. Therefore, a general diffusion-elimination model is presented from which maximal rate of elimination (Em), individual anaerobic threshold (IAT), gradient between muscle and blood ($\Delta C - \Delta C_{Em}$), muscle volume working above the IAT (Vm), individual membrane constant (Mc), quantity of lactate accounting for lactate gradient (A_{grad}), and whole body lactate (A_{net}) can be obtained. For demonstration purposes, this model was applied to a highly trained athlete. In this example, all constants and variables mentioned above as well as an equation reflecting individual lactate kinetics were calculated. Furthermore, the IAT was determined in 61 athletes participating in different events. In general, it can be demonstrated that with increasing aerobic capacity the lactate concentration at the IAT decreases. The lactate concentration at the IAT varies interindividually within broad limits, thus emphasizing the need for individual assessment.

Key words: lactate kinetics, physical exercise, diffusion, elimination, individual anaerobic threshold

Introduction

Experimental evidence indicates a threshold representing a balance between removal and release of lactate from and into the plasma compartment (1, 9). Regarding the onset of dissociation of muscle and blood lactate concentration levels (6), this threshold was considered at a blood lactate level of 4 mmol/l (9, 11) or a predetermined inclination of the blood lactate curve (7). This threshold was defined as the anaerobic threshold (AT) (7, 9) or aerobic-anaerobic threshold (11), whereas the point of increase of lactate from the baseline concentration level was defined as the aerobic threshold (9), formerly called the anaerobic threshold (16, 17). In general, this is a useful approach, though in some cases this consideration did not appear to be satisfactory. Considering the anaerobic threshold at the fixed value of 4 mmol/l lactate does not take into account the individual kinetics of the blood lactate concentration curve. Therefore, the individual anaerobic threshold can be located above or below the 4 mmol/l blood lactate level. In this study, the lactate distribution in blood and muscle compartments during stepwise increasing work loads was determined by introducing a general diffusion-elimination model derived from blood lactate kinetics during exercise and the post-exercise period. By means of this model, the individual anaerobic threshold (IAT) was determined at individual lactate concentration levels and individual blood lactate inclination rates.

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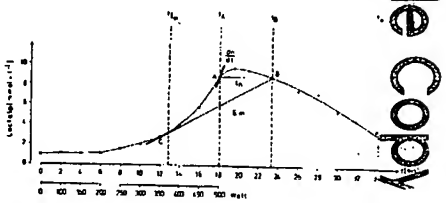

Fig. 1 Lactate kinetics during exercise with stepwise increasing work loads in an international rowing champion (abbreviations see p 164)

Material and Methods

Considering diffusion through biologic membranes (Ep. 1), the progressive increment of the blood lactate concentration during progressive work load (Fig. 1) reflects the increase of the lactate gradient ΔC between working muscle and blood.

$$\text{Diffusion:} \quad \left|\frac{dn\,(t)}{dt}\right| = Mc \cdot \Delta C \qquad (1)$$

Simultaneously, the rate of lactate elimination E (t) must be considered (4, 15, 18). When the lactate concentration curve starts to rise, the increase in the diffusion rate exceeds the increase in the elimination rate. Near the steepest part of the curve in point t_A, the increment in the elimination rate can be considered negligible in relation to the increment in the diffusion rate. It can be concluded that the rate of elimination approaches a maximum (Eq. 1a).

$$\text{Elimination:} \quad -\frac{dm\,(t)}{dt} = E\,(t)$$

$$\rightarrow Em = \text{const if } t \rightarrow t_A \qquad (1a)$$

If a certain rate of diffusion is exceeded, an increase of the blood lactate concentrations in the initial post-exercise period ($t > t_A$, Fig. 1) can be observed.

Equation 2 defines the point of time and work load where the maximal rate of elimination is in equilibrium with the rate of diffusion. This condition defines the IAT:

if $t = t_{Em}$

$$\left|\frac{dn\,(t)}{dt}\right| = Em = Mc \cdot \Delta C_{Em} \qquad (2)$$

From Eq. 1 and 2, Eq. 3 is derived, describing lactate kinetics during exercise above the IAT:

if $t > t_{Em}$

$$\left|\frac{dn\,(t)}{dt}\right| = Em + Mc \cdot (\Delta C - \Delta C_{Em}) \qquad (3)$$

$$\left|\frac{dn\,(t)}{dt}\right|_{max} = Em + MC \cdot (\Delta C_{max} - \Delta C_{Em}) \qquad (3a)$$

At point of time t_A (Fig. 1, cessation of work), the rate of diffusion and lactate gradient are maximal (Eq. 3a).

In the post-exercise period ($t > t_A$), the lactate gradient and consequently the rate of diffusion decrease (2). Figure 2a shows for different gradients (in t_A) and their diffusion rates the points of time where elimination $Em \cdot (t - t_A)$ meets diffusion $\int_{t_A}^{t > t_A} \frac{dn\,(t)}{dt}\,dt$. These are the intersection points of the straight line $Em\,(t - t_A)$ with the curves representing different amounts of diffusion $\int_{t_A}^{t > t_A} \frac{dn\,(t)}{dt}\,dt$. Diffusion and elimination acting simultaneously lead to points of intersection with the t-axis as represented in Fig. 2b (gradient ΔC_{Em} does not result in lactate increase in the post-exercise period). In the blood lactate concentration curve (Fig. 1), this condition is attained at time point t_B where the decreasing lactate concentration equals the concentration at point t_A. Time interval $(t_B - t_A)$ is named t_n.

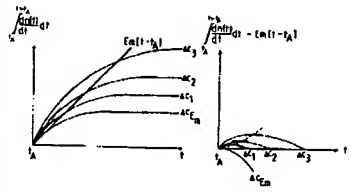

Fig. 2a Time course of diffusion ($\int_{t_A}^{t > t_A} \frac{dn(t)}{dt}\,dt$) according to different gradients (ΔC_{Em} to ΔC_3) and elimination $Em\,(t - t_A)$ presented separately.
Fig. 2b Time course of diffusion and elimination acting simultaneously.

Em is defined as decrease of concentration with time:

$$Em = \frac{dC}{dt}$$

Concentration is defined as quantity devided by volume:

$$C = \frac{A\ (\text{quantum})}{V\ (\text{volume})}$$

$Em \cdot t_n$ determined in blood volume (Vb) reflects the decrease of $\Delta C_{max} - \Delta C_{Em}$ in the muscle volume working above the IAT (Vm). Regarding a given quantum (A), Eq. 4 is derived:

$$Em \cdot t_n\,(Vm + Vb) = (\Delta C - \Delta C_{Em}) \cdot Vm \qquad (4)$$

$$\left(1 + \frac{Vb}{Vm}\right) Em \cdot t_n = (\Delta C - \Delta C_{Em})$$

Eq. 4 results from Eq. 3a and 4:

if $t = t_A$

$$\left|\frac{dn(t_A)}{dt}\right| = Em + Mc \cdot Em \cdot t_n \left(1 + \frac{Vb}{Vm}\right) \qquad (5)$$

In contrast to Eq. 5, the gradient in t_A can be followed up in the post-exercise period only as discussed in Fig. 2a: in $\overline{t_B\ t_A}$

$$Em \cdot t_n = \int_{t_A}^{t_B} \frac{dn\,(t)}{dt}\,dt = \Delta C - \Delta C_{Em}$$

Substitution into Eq. 3a results in:

in $\overline{t_B\ t_{Em}}$

$$\left|\frac{dn\,(t_A)}{dt}\right| = Em + Mc \cdot Em \cdot t_n$$

Mc expresses the increase of the rate of diffusion per gradient increase of 1 mmol/l. Its dimension is min^{-1} (1/dt), and it is defined for the time interval $t_A - t_{Em}$ only. Therefore, the above equation can be written:

$$\left|\frac{dn\,(t_A)}{dt}\right| = Em + \frac{1}{dt} \cdot Em \cdot t_n$$

Integral within time limits $t_A - t_{Em}$ results in:

$$\int_{t_{Em}}^{t_A} \frac{dn\,(t_A)}{dt}\,dt = \int_{Em}^{t_A} Em \cdot dt + \int_{t_{Em}}^{t_A} \frac{Em \cdot t_n}{dt}\,dt$$

$$f(t_A) = Em\,(t_A - t_{Em}) + Em \cdot t_n \qquad (6)$$

Regarding Fig. 1, Eq. 7 results from Eq. 6 demonstrating that every $(Em \cdot t_n)$ is defined by the blood lactate concentration curve $f\,(t_A)$ and the straight line resulting from $Em\,(t_A - t_{Em})$ and that all points B' are located on the straight line $Em\,(t_B - t_{Em})$, which is the tangent from a given B to the blood lactate curve.

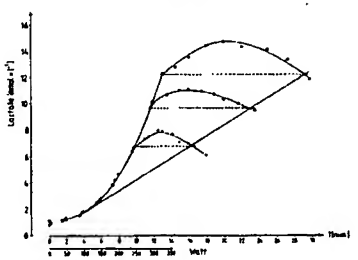

Fig. 3 Lactate kinetics in an untrained individual at different work loads. o—o exercise to exhaustion; •—• exercise up to 300 W; x—x exercise up to 250 W.

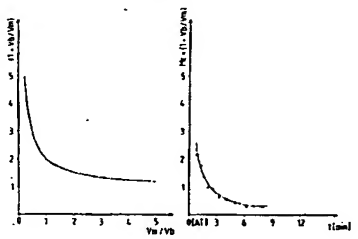

Fig. 4a Relationship of factor (1 + Vb/Vm) and increasing muscle volume (Vm/Vb).
Fig. 4b Time course of Mc (1 + Vb/Vm) as determined in • = a regional class long-distance runner; o = a German elite long-distance runner (up to 10,000 m); x = a German champion in 3000 m; + = an international rowing champion (Fig. 1).

$$f(t_A) = Em\,(t_A - t_{Em}) + Em\,(t_B - t_A) = Em \cdot (t_B - t_{Em})$$
$$Em\,(t_B - t_A) = f(t_A) - Em\,(t_A - t_{Em}) \qquad (7)$$

The contact point marks the individual anaerobic threshold (IAT), the ascent of the tangent the individual maximal elimination rate (Em) according to Eq. 2.

This can be confirmed experimentally. Figure 3 shows lactate kinetics for maximal and submaximal work loads on the bicycle ergometer in an untrained individual (different symbols mark different tests on consecutive days).

For each point of the blood lactate curve, the term Mc. (1 + Vb/Vm) can be calculated by substituting for Em, tn, and dn (t)/dt into Eq. 5. Figure 4b depicts the changes of this term with time in three well-trained long-distance runners and the rower whose lactate curve is presented in Fig. 1 (time 0 marks IAT). Figure 4a shows changes of the factor (1 + Vb/Vm) with increasing muscle volume working above the IAT (expressed as multiple of the blood volume). The two curves are almost identical in shape. Accordingly, changes of Mc (1 + Vb/Vm) with time are considered to reflect changes of the muscle volume working above the IAT. Changes of Vm/Vb with time are determined by means of the standard curve in Fig. 4a, leading to the individual membrane constant (Mc). For every point of a given blood lactate curve above the IAT, the corresponding lactate gradient can be calculated from:

$$\frac{\left|\frac{dn\,(t)}{dt}\right| - Em}{Mc} = \Delta C - \Delta C_{Em}$$

Subsequently, it is easy to calculate the increment of the gradient per work load increment as well as the increase of muscle volume working above the IAT (Vm/Vb).

The amount of lactacid energy production can be calculated from the amount of lactate produced: a gradient multiplied by volume results in the quantity of lactate accounting for the lactate gradient:

$$A_{grad} = Em \cdot t_n\,(Vm/Vb + 1)\,Vb$$

Vb can be estimated by nomogram or from tables (Wiss. Tabellen, Dokumenta Geigy).

Determination of lactate distribution in body fluids is controversial (3, 13) as blood concentration levels must be considered to account for concentration levels in interstitial fluids as well. As elimination is defined as the decrease of lactate concentration with time in blood and muscle volume (Vm + Vb), the total amount of body lactate at time point t_A (net lactate production: A_{net}) can be calculated by Em multiplied by the time interval from t_A (cessation of work) to the point of time where the lactate concentration in the post-exercise period equals the lactate concentration in t_{Em} (t_{net}):

$$A_{net} \cdot Em \cdot t_{net} \cdot (Vm/Vb + 1) \cdot Vb$$

As elimination is considered to occur during exercise as well, total lactate production (A_{tot}) can be obtained from calculation of Em over the time interval $t_{tot} = (t_x - t_{Em})$:

$$A_{tot} = Em \cdot t_{tot} \cdot (Vm/Vb + 1) \cdot Vb$$

Sixty-two athletes from different events were subjected to different exercise tests (see data in Table 1); 38 males were tested on a motor-driven treadmill and 16 males and 8 females on an electrically braked bicycle ergometer.

1. Bicycle Ergometer

Swimmers (females):
initial load 50 W, increment 50 W every 3 min

Swimmers and speed skaters (males):
initial load 100 W, increment 50 W every 3 min

2. Treadmill

Physical education students and handball players:
initial speed 6 km/h at a slope of 5%, increment 2 km/h every 3 min

Long-distance runners:
initial speed 8 km/h at a slope of 5%, increment 2 km/h every 3 min

Tab. 1 Data on 62 participating athletes

Groups	n	Age (years)	Height (cm)	Weight (kg)	Heart volume (ml)	Heart volume (ml/kg)	$\dot{V}O_2$/kg (ml · min^{-1})
L (r)	8	24.2 ± 6.0	177 ± 7.1	66.2 ± 8.9	980 ± 155	14.9 ± 1.3	72.4 ± 7.4
HB	16	23.9 ± 3.0	185 ± 7.0	85.0 ± 9.8	1008 ± 155	11.9 ± 1.0	55.2 ± 3.8
ST	14	25.3 ± 3.0	179 ± 4.3	70.8 ± 5.8	–	–	55.6 ± 7.3
SS	7	22.3 ± 2.0	180 ± 2.9	78.0 ± 1.9	928 ± 116	11.9 ± 1.4	58.2 ± 6.2
S ♂	9	18.1 ± 3.2	183 ± 4.8	75.0 ± 6.2	1073 ± 80	14.2 ± 1.4	58.6 ± 3.9
S ♀	8	17.6 ± 4.0	169 ± 5.3	61.7 ± 7.4	710 ± 113	11.5 ± 1.3	51.0 ± 6.9

Tab. 2 Effect of exercise with stepwise increasing work loads above the individual anerobic threshold on individual lactate kinetics

Exercise min	W	Lactate mmol · l^{-1}	dn(t)/dt mmol·l^{-1}·min^{-1}	$\Delta C-\Delta C_{Em}$ mmol · l^{-1}	Vm/Vb	Em · tn mmol · l^{-1}	A_{grad} mmol	A_{net} mmol	A_{tot} mmol
12.5	363	3.0	0.516	0	0	0	0		
14	400	3.95	0.75	0.83	0.26	0.17	1.5		
16	450	5.9	1.2	2.35	0.85	1.08	14.0		
18	500	8.8	1.8	4.34	2.27	3.01	68.6	174.8	(241.5)

Tab. 3 Work load and lactate concentration in blood at the individual anaerobic threshold in treadmill and bicycle exercise in different events; means, standard deviations, and upper and lower limits of values

Treadmill exercise

Event	n	Work load IAT (km/h, 5% incl.) $\bar{x}$	range	Lactate concentration at IAT (mmol · l^{-1}) $\bar{x}$	range
L (r)	7	14.6 ± 1.1	13.5 – 15.8	2.1 ± 0.5	1.4 – 3.0
HB	16	10.5 ± 0.96	9.0 – 12.0	3.91 ± 1.1	2.0 – 5.7
ST	14	9.5 ± 1.6	7.8 – 12.0	4.6 ± 1.2	3.0 – 7.5

Bicycle exercise

Event	n	Work load IAT (W) $\bar{x}$	range	Lactate concentration at IAT (mmol · l^{-1}) $\bar{x}$	range
SS	7	280 ± 60	200 – 325	3.6 ± 0.8	2.5 – 4.6
S ♂	9	254 ± 20.6	225 – 300	3.9 ± 0.8	2.7 – 6.6
S ♀	8	176 ± 33.7	125 – 225	3.2 ± 0.6	2.4 – 4.3

Heart rate was determined from ECG recording during the last seconds of each work load. Oxygen uptake was measured continuously with an open system. Arterialized blood for enzymatic determination of lactate concentration (5) was taken with heparinized capillaries from the hyperemic earlobe at rest, at the end of each work load, and in the post-exercise period at 1, 2, 5, and 10 min from the termination of exercise.

Results

According to this diffusion-elimination model, individual assessment of the constants IAT, Em, Mc and variables dn (t)/dt, $\Delta C-\Delta C_{Em}$, and Vm/Vb was done by a computer program in 61 athletes. The lactate concentration curve in Fig. 1 (international champion in rowing) may serve as an example (Vb = 7.0 l):

Data:

IAT = 363 W (3.0 mmol/l lactate)
Em = 0.516 mmol · l^{-1} · min^{-1}
Mc = 0.292 min^{-1}

The gradient at the IAT (derived from Eq. 2):

ΔC_{Em} = Em/Mc = 1.76 mmol · l^{-1}

Individual lactate kinetics follow Eq. 5:

$dn(t)/dt = 0.516\ [1 + 0.292 \cdot t_n\ (1 + Vb/Vm)]$

The effect of exercise with stepwise increasing work loads above the IAT on individual lactate kinetics is shown in Table 2. The individual evaluation of lactate kinetics as demonstrated in Table 2 shows that the acceleration of the increment of the blood lactate curve (dn(t)/dt) is paralleled in the increment of the gradient ΔC.

The increase of Vm/Vb indicates the increase of the muscle volume working above the IAT (Vm). The maximal value in 62 athletes was 4.2. It never approached the physiologic limit of 5–6 [Wiss. Tab. Dok. Geigy, (10)].

Means of lactate concentration levels in blood during the exercise and post-exercise period were calculated for each group listed in Table 1. Figures 5 and 6 show the group means of the anaerobic threshold as determined from the

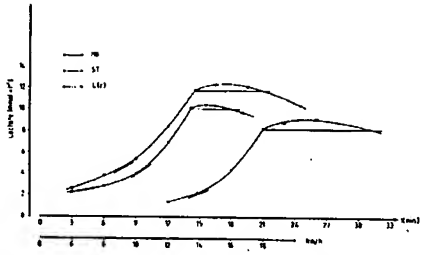

Fig. 5 Lactate kinetics in mean lactate concentration curves according to events (Table 1, treadmill exercise).
HB = handball players; ST = physical education students;
Lr = long-distance runners (solid bars indicate tangent at IAT)

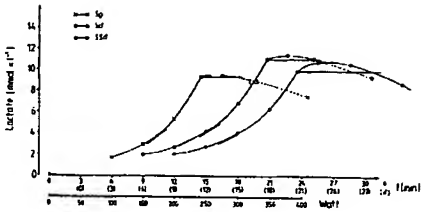

Fig. 6 Lactate kinetics in mean lactate concentration curves according to events (Table 1, bicycle exercise).
S = swimmers, male and female; SS = male speed skaters;
(solid bars indicate tangent at IAT)

mean concentration curves. In addition, from each individual curve the anaerobic threshold was calculated. Table 3 shows means as well as upper and lower limites of lactate concentration and work load as determined individually.

Critical Evaluation of Experimental Settings

In conventional bicycle ergometer and treadmill tests (8), stepwise increasing work loads are used. Intermediate work loads are calculated by interpolation. To follow the relationship between work load and physiologic response more closely, exercise tests with continuously increasing work load may turn out to be preferable. Unlike in bicycle ergometer tests, blood sampling in treadmill tests requires interruption of work at the end of each interval, which leads to a decrease of the lactate gradient between blood and muscle. Whereas in treadmill tests blood is taken immediately after termination of work, in bicycle ergometer tests this can be done immediately before termination.

Discussion

The higher the work load in stepwise tests, the more the rate of elimination remains behind the rate of diffusion, leading to an increasing acceleration of the blood lactate curve.

By means of the model presented, the maximal rate of elimination (in t_A) is determined at the blood lactate concentration curve by means of a tangent. The contact point defines the individual anaerobic threshold (IAT).

The assumption that maximally induced rates of elimination (Em) do not change during inactivity in the post-exercise period seems to disagree with experimental evidence, indicating that work loads below the onset of blood lactate accumulation induce a faster decrease of the blood lactate concentration (1, 18, 4). During the first minutes of recovery, this effect appears to be negligible in magnitude. The experimental evidence presented in Fig. 3 supports this assumption, as rates of elimination seem to be similar for different t_n intervals. Whether this holds for very long t_n intervals or time intervals t_{net} or t_{tot} cannot yet be decided. It may turn out to be favorable to apply light work loads near the aerobic threshold (9) in the post-exercise periods, thus ensuring maximal rates of elimination.

It is an advantage of this model that for the assessment of total lactate turnover the magnitude of the lactate space, the muscle volume working above the IAT, and the maximal rate of elimination must not be substituted for by estimated values (3, 13). Evaluation of the amount of lactate accounting for a given gradient (A_{grad}) or net lactate production (A_{net}) takes into account individual lactate turnover not only in one compartment (3, 12–14) but in Vm and Vb simultaneously.

The results indicate that individual determination of the anaerobic threshold or aerobic-anaerobic threshold at fixed lactate concentrations (9, 11) or fixed increments of the lactate concentration (7) is not possible. Because of individual lactate kinetics, higher as well as lower lactate concentrations than 4 mmol/l (9, 11) were found within almost all study groups (Figs. 5 and 6, Table 3). The means of lactate concentration at the IAT in groups of untrained subjects or athletes not especially endurance-trained was found near 4 mmol/l, whereas in endurance-trained subjects (especially in highly trained long-distance runners), it was found to be distinctively lower (Table 3). Thus, in cross-sectional studies, it has to be taken into account that determination of the AT at fixed lactate values may lead to wrong evaluation of endurance capacity. Individual lactate kinetics require individual determination of the anaerobic threshold (IAT).

A paper dealing with 50-min tests at the IAT and at a fixed lactate concentration is in preparation. It will be published in one of the next issues of this journal.

Abbreviations

Symbol	Dimension	Definition
A_{grad}	mmol	Amount of lactate accounting for the lactate gradient
A_{net}	mmol	Total amount of body lactate in t_A
A_{tot}	mmol	Total contribution of anaerobic energy metabolism to exercise in t_A

Abbreviations continued:

Symbol	Dimension	Definition
ΔC_{Em}	$mmol \cdot l^{-1}$	Lactate gradient at the IAT
ΔC_{max}	$mmol \cdot l^{-1}$	Lactate gradient at t_A
$dn(t)/dt$	$mmol \cdot l^{-1} \cdot min^{-1}$	Rate of diffusion
Em	$mmol \cdot l^{-1} \cdot min^{-1}$	Maximal rate of elimination
IAT	–	Individual anaerobic threshold
Mc	min^{-1}	membrane constant: increase of the rate of diffusion if the gradient $\Delta C_{max} - \Delta C_{Em}$ is increased by 1 $mmol \cdot l^{-1}$
t_A	min	Point of time of cessation of work in exercise with stepwise increasing work loads
t_B	min	Point of time when the lactate concentration in post-exercise period meets the lactate concentration in t_A
t_{Em}	min	Point of time during exercise with stepwise increasing work loads describing the IAT
t_n	min	Time interval ($t_B - t_A$) needed for elimination of A_{grad}
t_{net}	min	Time interval ($t_X - t_A$) needed for elimination of A_{net}
t_{tot}	min	Time interval ($t_X - t_{Em}$) needed for elimination of A_{tot}
t_X	min	Point of time when lactate concentration in post-exercise period meets lactate concentration in t_{Em}
Vb	l	Blood volume
Vm	l	Muscle volume working above IAT

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Prof. Dr. W. Kindermann, Department of Sports and Performance Medicine, University of Saarland, D-6600 Saarbrücken, FRG

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Onset of Blood Lactate Accumulation and Enzyme Activities in M. Vastus Lateralis in Man

B. Sjödin, I. Jacobs, and J. Karlsson

Laboratory for Human Performance, Dept. of Clinical Physiology, Karolinska Hospital and National Defense Research Institute, Stockholm, Sweden

Abstract

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In an earlier study, we reported close relationships between marathon running performance and the running velocity (V) at which the "onset of blood lactate accumulation" (V_{OBLA}) occurs in a group of marathon runners. Using biopsy material from the m. vastus lateralis of the same subjects (n = 19), we have evaluated the relationship of V_{OBLA} to different muscle enzyme activities together with muscle fiber composition and capillary density in the present study. The activities of lactate dehydrogenase (LDH EC 1.1.1.27), phosphofructokinase (PFK EC 2.7.1.11), and citrate synthase (CS EC 4.1.3.7) were determined. V_{OBLA} was negatively correlated to LDH (r = –0.54) and PFK/CS (r = –0.68). Using multiple regression analysis, the PFK/CS ratio together with the capillary density accounted for 81% of the variation in V_{OBLA}. Absolute training kilometrage was the most significant variable measured and accounted for 77% of the variation in V_{OBLA}. Subjects were divided into elite runners (n = 6) and nonelite runners (n = 13) for an additional analysis of the relationship between V_{OBLA} and the ratios of PFK/CS or LDH/CS. Significant relationships between V_{OBLA} and the ratios were observed only in the nonelite runners (r = –0.77 and –0.66, respectively). The vertical distances between the regression lines for these two subject groups could not be explained only on the basis of the enzyme activity ratios. A greater adaptation to fat combustion in the elite runners might explain the disproportionally high V_{OBLA} in relation to the PFK/CS or LDH/CS activity ratios.

Key words: blood lactate, muscle fiber type, enzymes, endurance exercise

Introduction

The running velocity corresponding to onset of blood lactate accumulation (V_{OBLA}) has been shown to be closely related to performance capacity in long-distance running (5, 23). It is also documented that the absolute as well as the relative exercise intensity at which blood lactate starts to accumulate is higher for endurance-trained subjects than for untrained subjects (3, 14, 18, 21).

Muscle lactate accumulation (14) as well as lactate release (8) at given submaximal work loads are lower after endurance training and related to an increased muscle tissue respiratory capacity as indicated by succinate dehydrogenase activity.

Tesch has demonstrated a positive relationship between the frequency of type II or fast twitch (FT) muscle fibers and lactate accumulation at onset of exercise under "non-steady state" (transient) conditions (26). He also has observed a higher lactate release to the blood per unit of lactate formed in subjects rich in type I or slow twitch (ST) muscle fibers than in subjects rich in FT fibers (personal communication). A number of studies in man have demonstrated a higher oxidative potential in ST fibers than in FT fibers, which is augmented by endurance training (e.g., 8).

During muscular exercise, the extent of lactate formed from carbohydrate metabolism is a function of the balance between glycolytic stimulation and the capacity of the muscular respiratory system. Ivy et al. (9) reported a direct relationship between onset of plasma lactate accumulation (OPLA) and the rate of oxygen consumption in muscle homogenate when pyruvate was added as the substrate.

The present study was performed to further evaluate how the activity potential of the glycolytic and oxidative enzyme systems, plus muscle fiber composition, will influence blood lactate accumulation expressed as V_{OBLA}.

Material and Methods

Subjects

Nineteen marathon runners participating in Stockholm's Marathon, 1979, gave their informed consent to participate in this study. Their age, height, and weight were (mean ± SD) 32 ± 7 yrs, 179 ± 6 cm, 78 ± 7.9 kg.

The group was divided into two subgroups based on marathon running records and training background. Subgroup A (n = 6) was characterized as "elite runners" with personal marathon bests between 2.18–2.40 h and had been training more than 100 km per week for at least 5 years. Their mean training volume per week 2 months before the race was 135 ± 34 km x week^{-1}. Subgroup B (n = 13) consisted of less experienced or "nonelite" runners with personal records above 3 h. They trained less than 100 km per week (mean ± SD: 53 ± 21 km x week^{-1}) during the 2 months before the competition.

Functional Tests

The running velocity corresponding to onset of blood lactate accumulation (V_{OBLA}) was determined during tread-